GPS All in View Time Transfer for TAI

- some results of recent studies at BIPM

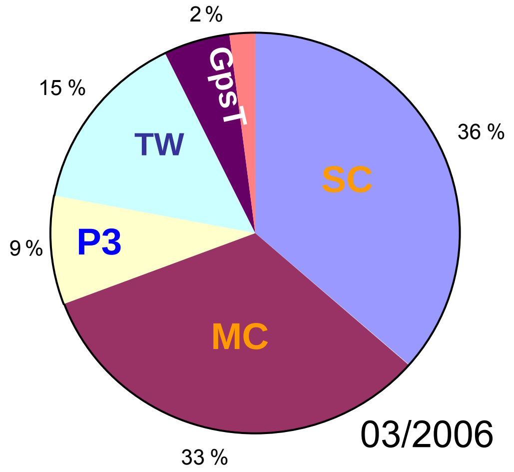
Z. Jiang and G. Petit
BIPM

Summary

- Different time transfer techniques used in TAI
- Common View and All in View
- Improvement in Uncertainty of time transfer: u_A
- Improvement in Uncertainty of UTC-UTC(k): u
- Change of UTC-UTC(k) when shift to AV
- Software and Internet availability

57 TAI Links in Circular T

- GPS SC: 1-frequency,1-channel C/A code
- GPS MC: 1-frequency,Multi-channel C/A code
- GPS P3: 2-frequency,Multi-channel iono-free P code
- TW: Two Way Time Transfer



Use the **Simultaneous Observation Condition**

→ **GPS Common View time transfer**

Other data and techniques available but not used in TAI:

- Glonass
- Redundant TW links
- IGS clock products
- GPS Carrier Phase (CP)
  - CP only
  - CP + P_codes (Global solution: example, the IGS clock products)
  - PPP (CP + P_codes: Single point solution, Precise Point Positioning), G. Petit
  - TW + GPS CP
  - TW + GSP CP + Codes (Single link or Network)

- No Use the **Simultaneous Observation Condition**

→ **GPS All in View time transfer**

EFTF 2006a: Comparison and Combination of TAI Time Links with continuous GPS Carrier Phase Results (joint study of BIPM and AIUB)

EFTF 2006b: Redundancy in TAI TW time transfer network

CPEM 2006: Recent Comparison of Time Transfer Techniques

TAI-CCTF 2006: This meeting - latest developments at BIPM
- This talk: All in view time transfer under the strict TAI Production Procedure: same data CA/P3 codes, CGGTTS format etc.

Other results by TAI study groups (Levine, Matsakis) and AOS, NICT, TL, KRISS (TW CP)

Common View

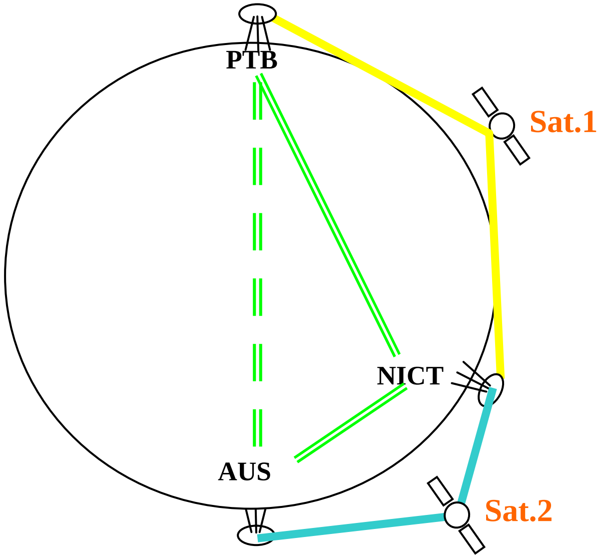
Condition **- Simultaneous Observation**

Advantages - Common errors are partly canceled :

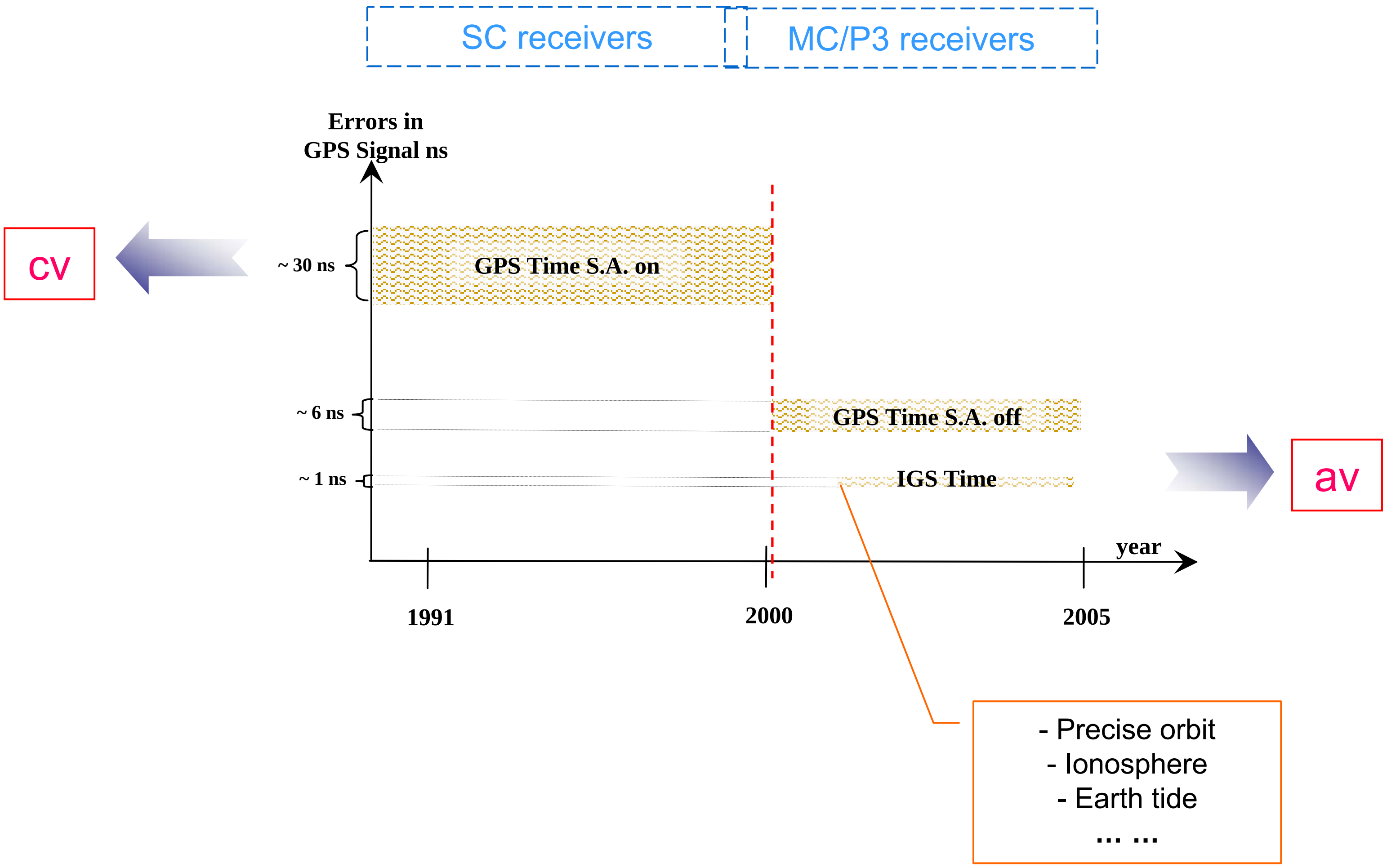
- GPS time signals, for ex. S.A.
- Satellite orbits
- Atmosphere delays

Disadvantages *(especially long baselines):*

- Observed satellite number reduced
- Low satellites, low S/N ratio
- Multi-Bridge System of TAI Network



Evolution of Errors in GPS Signals



All in View

Advantages:

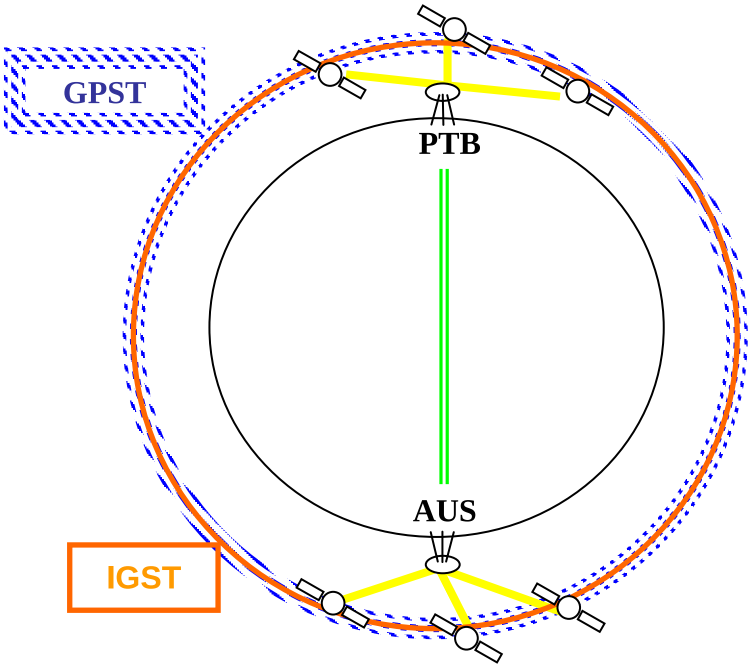
- Observes Satellites All in View
- High satellites and high quality
- No bridge lab for long distance

⇒ **Improved TAI time transfer stability without any new investment**

- No hardware updating required
- No change the current TAI procedure

Disadvantage:

- More rigorous data processing than CV



Improvement in Uncertainty of Time Link: u_A

-- Some statistics --

- Number of observed satellites/epochs ***!!***

  => Quality of satellite signals: noise - σ of smoothing residuals

  => Time stability

- Comparison with the independent and more accurate TW and PPP links (8 months: Oct. 2005 ~ May 2006)

Short-Middle Term Improvement in Uncertainty: u_A -- σ of Monthly Comparison to TW and PPP

Baseline	Obs. Type	Length/km	TW-AV	TW-CV	PPP-AV	PPP-CV	Gain
OP-PTB	P3	600	0.646	0.629			-2 %
NPL-PTB	P3	700	0.846	0.869	0.683	0.701	~ 2 %
	MC		1.356	1.364	1.420	1.388	~ 0 %
NPL-USNO	P3	6500	0.974	1.073	0.805	0.903	~ 10 %
USNO-PTB	P3	7000	0.753	0.912	0.614	0.830	~ 20 %
	MC		1.410	1.658	1.436	1.512	~ 9 %
KRIS-AUS	MC	7000	1.191	2.434			~ 50 %
OP-USNO	P3	7400	0.801	0.886	0.642	0.847	~ 15 %
NIST-PTB	SC	10 000	0.672	0.941			~ 28 %
NICT-PTB	P3	10600	1.305	1.990	0.956	1.686	~ 35 %
	MC		1.559	1.912	1.329	1.845	~ 20 %

(2.434-1.191)/2.434
= 0.511

Very Long baseline P3 Link TL - USNO

Clocks: H-MS
P3 link: 2-freqency P-code Receivers
Mjds: 53 852 ~ 886 (35 days, May 2006)

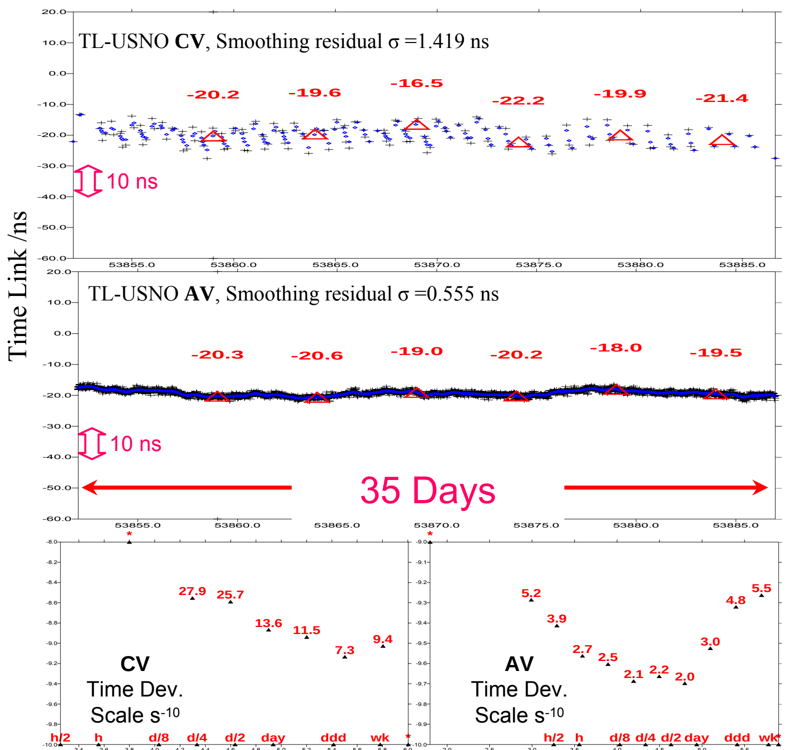
Distance : ~ 17, 000 km

CV Observation number : 150
AV Observation number : 3085

σ = 1.42 vs. 0.56 ns

Time Deviation (0.3~5h)

CV : ??? ~ 2.79 ns
AV : 0.52 ~ 0.21 ns



SC/MC Link: NIST - PTB

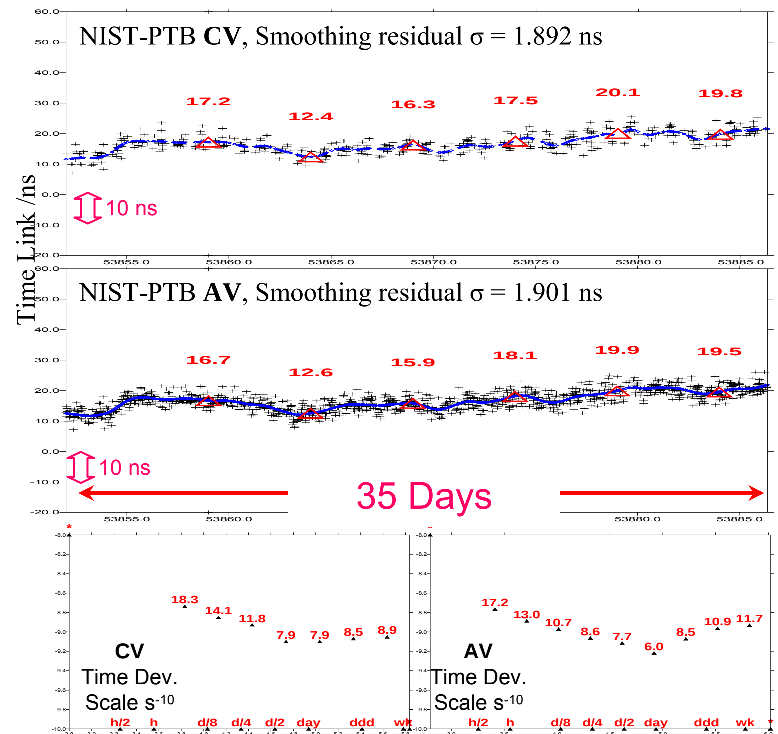
Clocks: H-MS vs. CS2
Single-Multi channel link: 1-freqency C/A –code Receivers
Mjds: 53 852 ~ 886 (35 days, May 2006)

Distance : ~ 10, 000 km

CV Observation number : 436 / σ = 1.89 ns
AV Observation number : 1148 / σ = 1.90 ns

Time Deviation (0.8~24h)
CV : ??? ~ 0.79 ns
AV : 1.72 ~ 0.60 ns

Comparison to TW
CV-TW : 0.91 ns
AV-TW : 0.65 ns



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MC Link: USNO(US) - NICT (Japan)

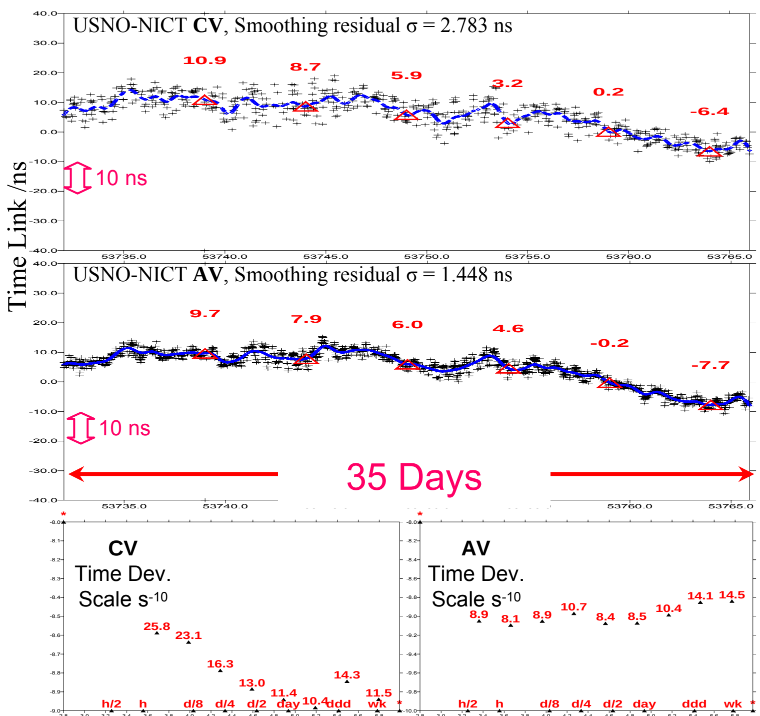
Clocks: H-MS vs. HP 5071
Multi-channel link: 1-freqency C/A -code Receivers
Mjds: 53 732 ~ 766 (35 days Jan. 2006)

Distance : ~ 15, 000 km

- **CV Observation number : 603**
- **AV Observation number : 1272**

- **σ = 2.78 vs. 1.45 ns**

Time Deviation (0.6~5h)
CV : ??? ~ 1.63 ns
AV : 0.89 ~ 1.07 ns



P3 Link: USNO(US) - NICT (Japan)

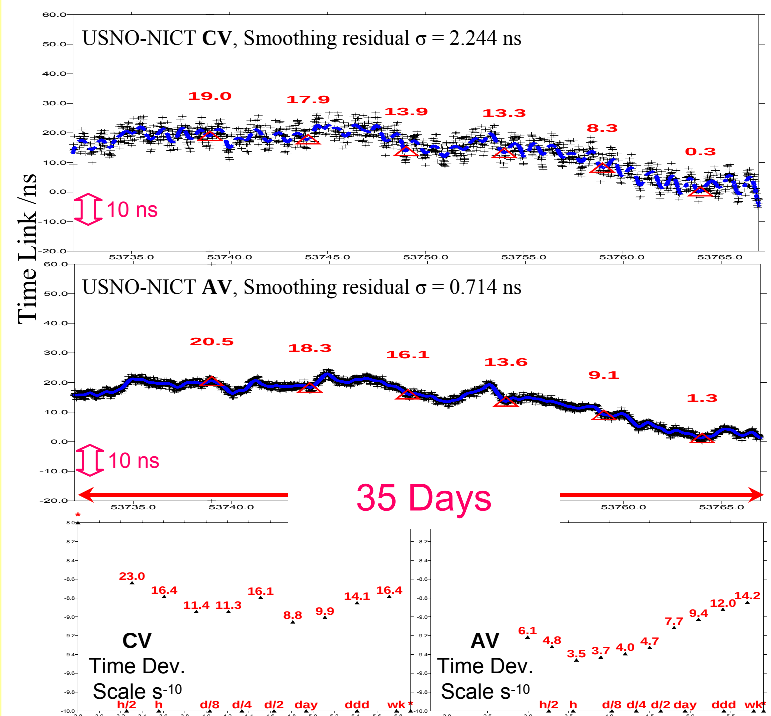
Clocks: H-MS vs. HP 5071
P3 link: 2-freqency P-code Receivers
Mjds: 53 732 ~ 766 (35 days Jan. 2006)

Distance : ~ 15, 000 km

- **CV Observation number : 1494**
- **AV Observation number : 3060**

- **σ = 2.24 vs. 0.71 ns**

Time Deviation (0.3~5h)
CV : ??? ~ 1.18 ns
AV : 0.61 ~ 0.4 ns



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Long Term Improvement in Uncertainty: u_A
-- σ of 4 Month Comparison to TW and PPP

Baseline	Obs. Type	Length/km	TW-AV	TW-CV	PPP-AV	PPP-CV	Gain
OP-PTB	P3	600	1.641	1.658			~ 1 %
NPL-PTB	P3	700	0.993	1.034	0.696	0.735	~ 4 %
	MC		1.550	1.538	1.340	1.320	~ 0 %
NPL-USNO	P3	6500	0.844	0.978	0.712	0.866	~ 14 %
USNO-PTB	P3	7000	0.787	0.948	0.583	0.822	~ 20 %
	MC		1.552	1.710	1.870	1.888	~ 4 %
KRIS-AUS	MC	7000	2.118	2.967			~ 20 %
OP-USNO	P3	7400	0.827	0.946	0.708	0.891	~ 15 %
NICT-PTB	P3	10600	1.173	1.938	0.933	1.663	~ 40 %
	MC		1.857	2.086	2.082	2.333	~ 11 %

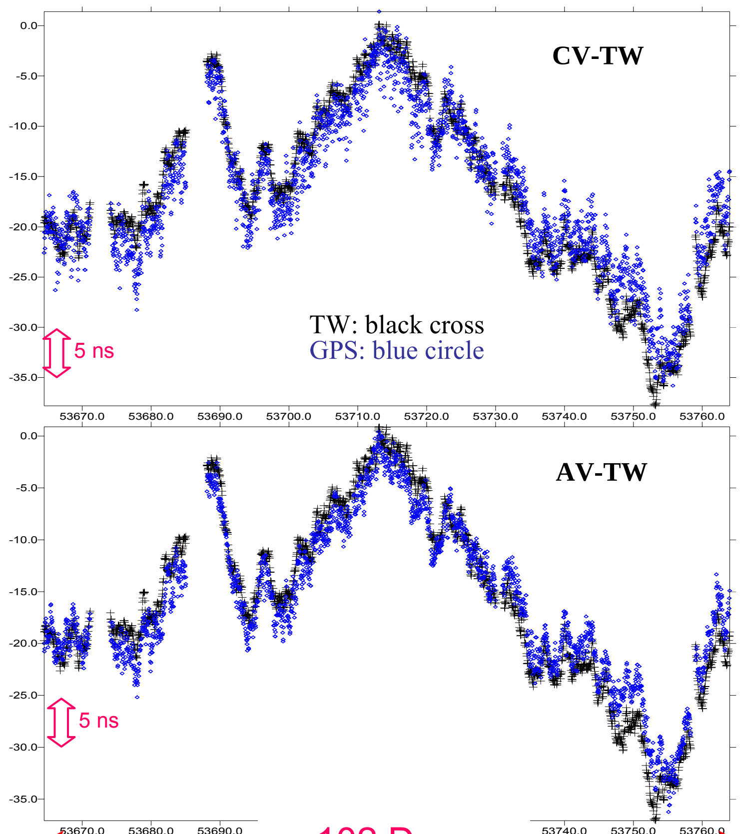
MC Link: NICT- PTB CV-AV Compared to TW

Multi channel link: 1-freqency C/A –code Receivers
Mjds: 53 664 ~ 763 (102 days Oct. 2005 – Jan. 2006)

Distance : ~ 10, 000 km

Differences of GPS CV-AV v.r.t. TW

σ of CV-TW = 2.086 ns
σ of AV-TW = 1.857 ns



102 Days

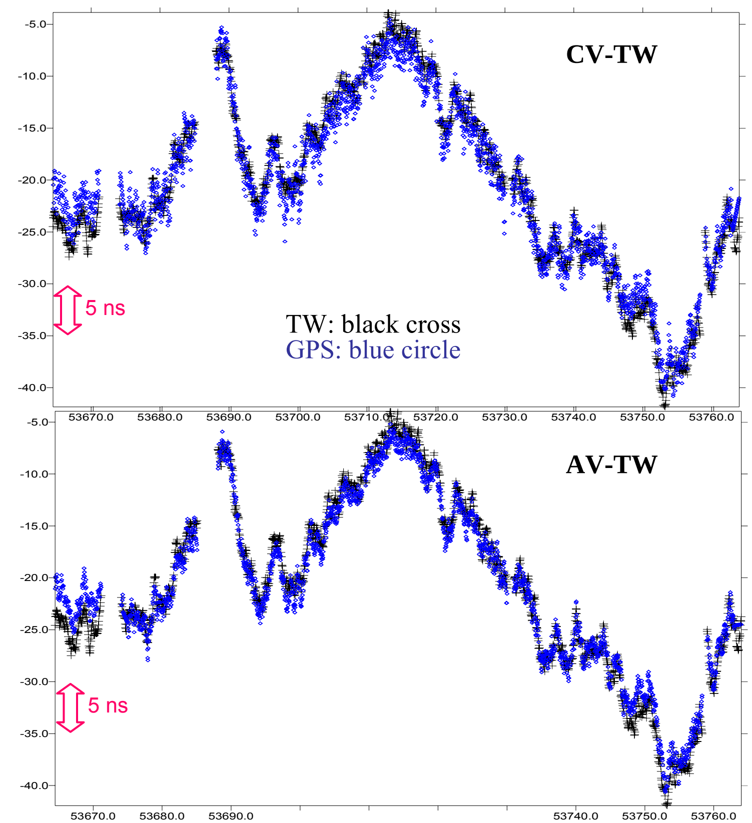
P3 Link: NICT- PTB CV-AV Compared to TW

P3 link: 2-freqency P-code Receivers
Mjds: 53 664 ~ 763 (102 days Oct. 2005 – Jan. 2006)

Distance : ~ 10, 000 km

Differences of GPS CV-AV v.r.t. TW

σ of CV-TW = 1.938 ns
σ of AV-TW = 1.173 ns



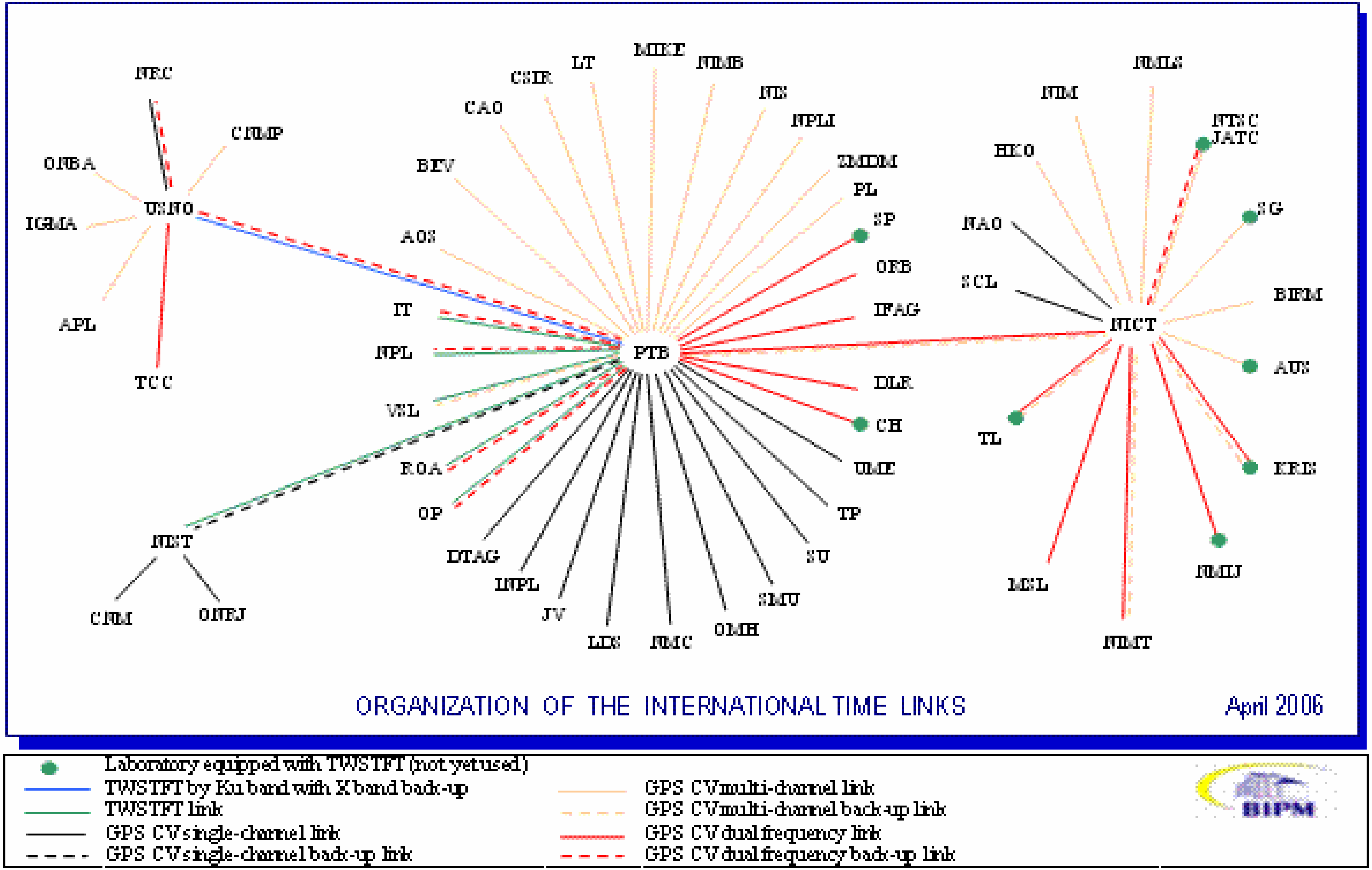
102 Days

Improvement in Total Uncertainty of UTC - UTC(k) due to the improved u_A and the direct AV linking: CV vs. AV (1/5)

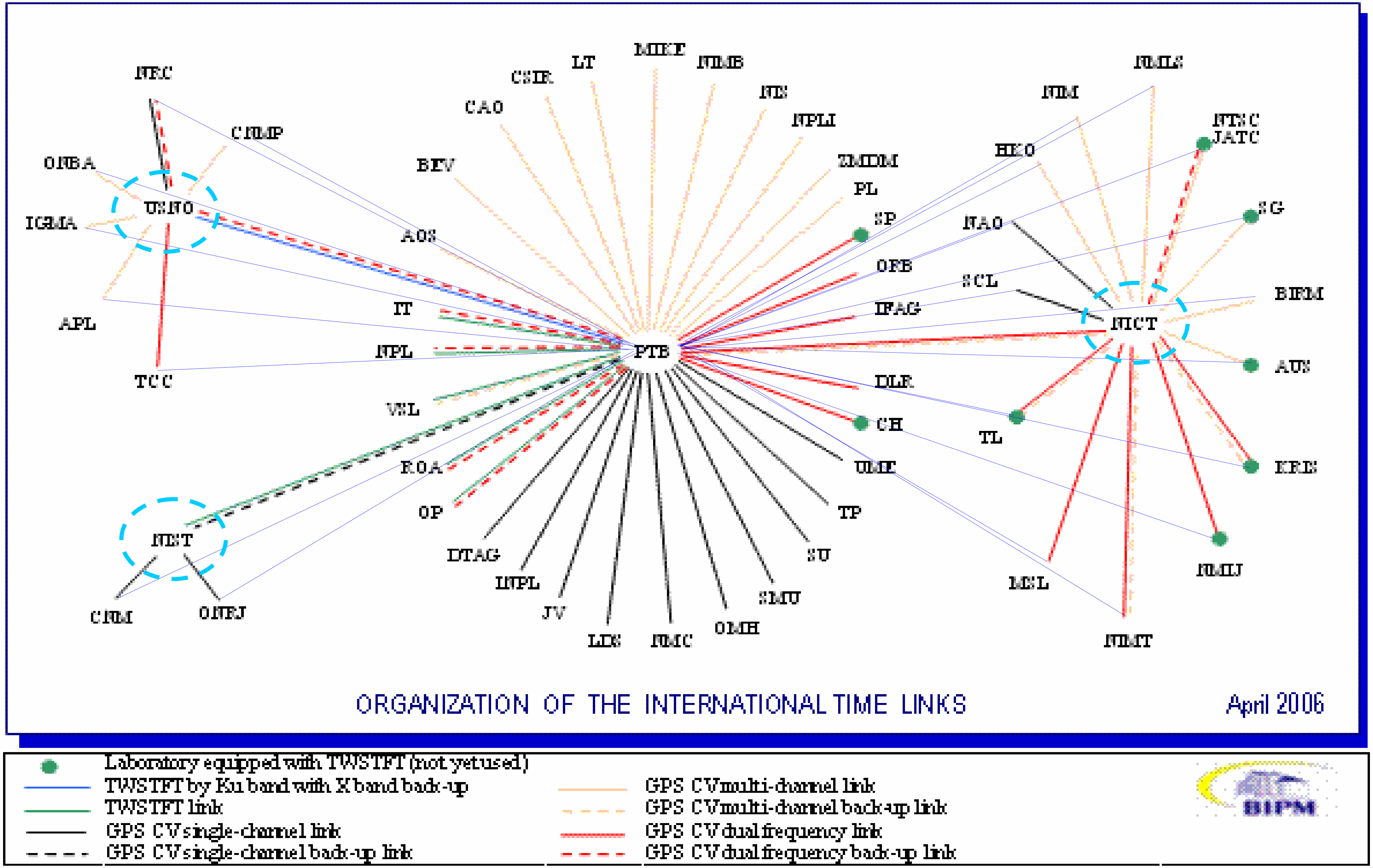
- Due to better time stability of AV than CV : $u_{A_{AV}} \leq u_{A_{CV}}$
- Due to '***direct***' AV link without pivot labs: pivoting errors u_A, $u_B \sim 0$
- ⇨ Total uncertainty of UTC-UTC(k) : $u_{AV} \leq u_{CV}$

  - Uncertainty UTC-UTC(k) is computed with current CirT procedure
  - Plots in this presentation are only the labs with their receivers calibrated: u_B < 10 ns, totally 30 labs over all 56 TAI labs for April 2006

Improvement in Uncertainty: CV links (2/5)



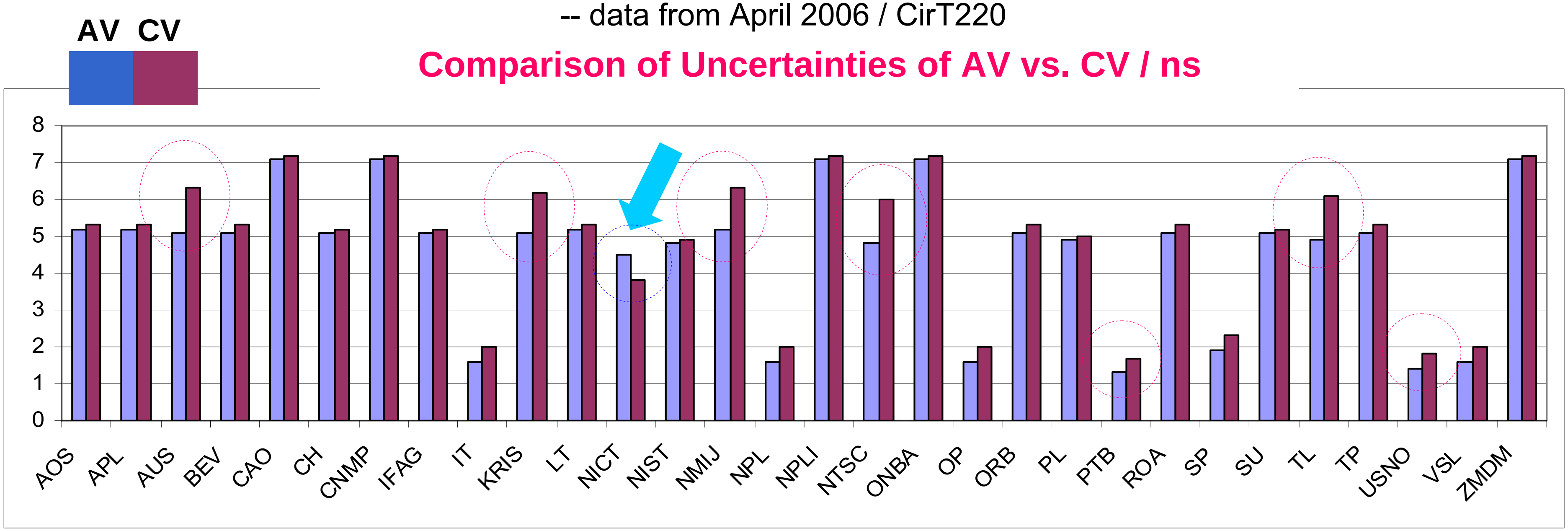
Improvement in Uncertainty: AV links (3/5)

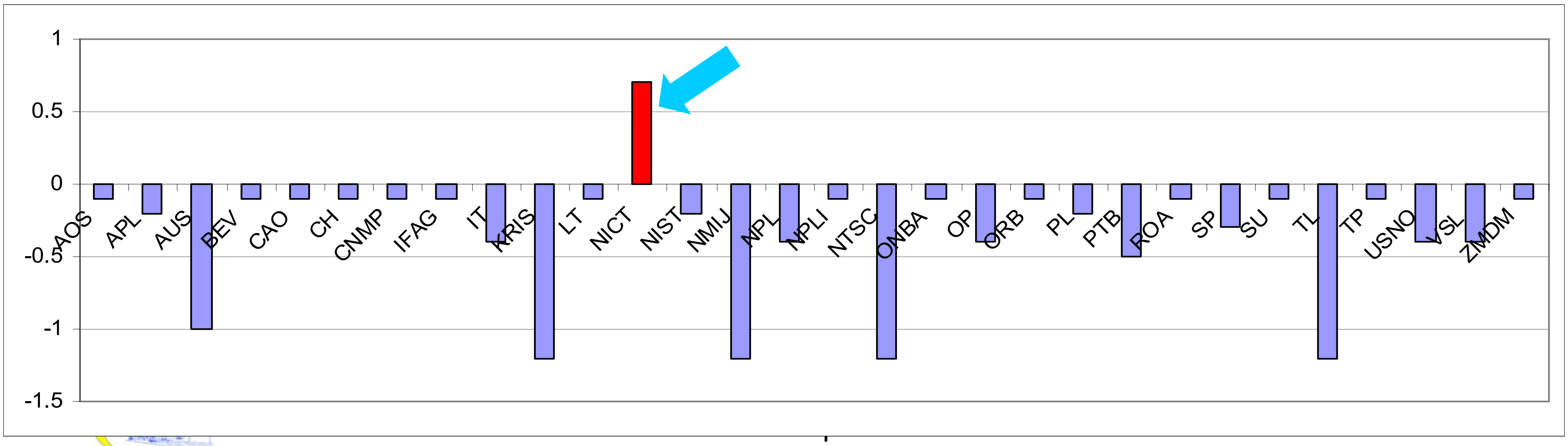


BIPM

Improvement in Total Uncertainty UTC-UTC(k) due to the *direct* AV linking (with $u_A = u_{A_{CV}}$) (4/5)

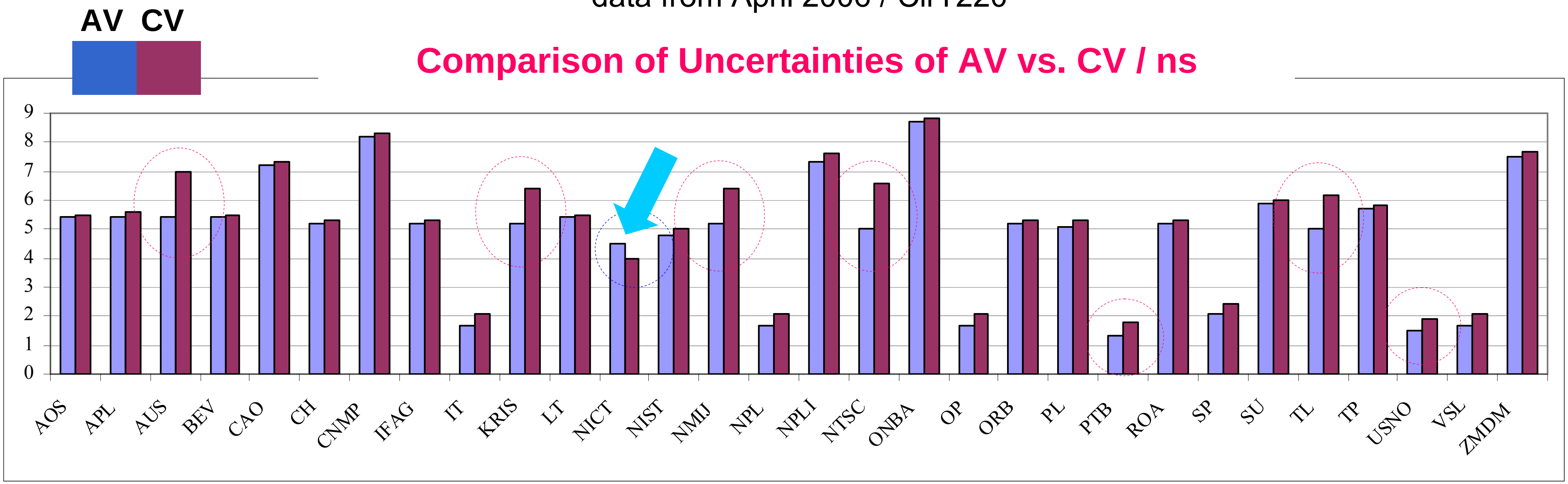
-- data from April 2006 / CirT220

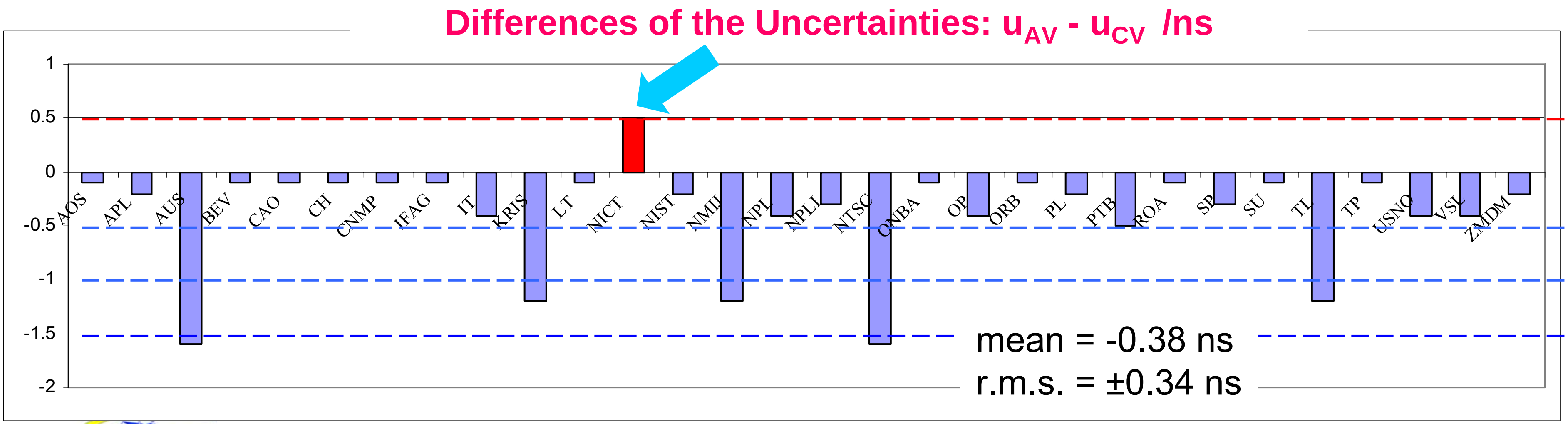




Improvement in Total Uncertainty UTC-UTC(k) due to the *direct* AV linking and the improved $u_{A_{AV}}$ (5/5)

-- data from April 2006 / CirT220

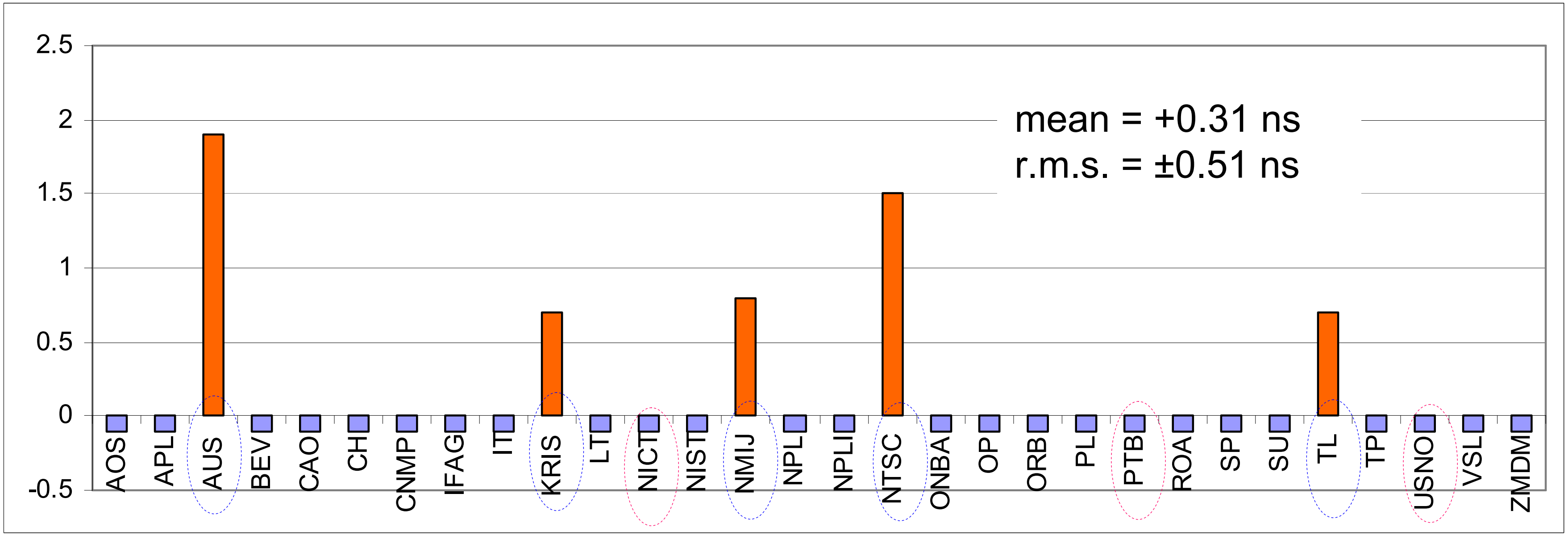




Change of UTC-UTC(k) when shift to AV

Differences between $[UTC\text{-}UTC(K)]_{AV}$ and $[UTC\text{-}UTC(K)]_{CV}$

(MJD 53839 June 2006 CirT220)



Conclusion

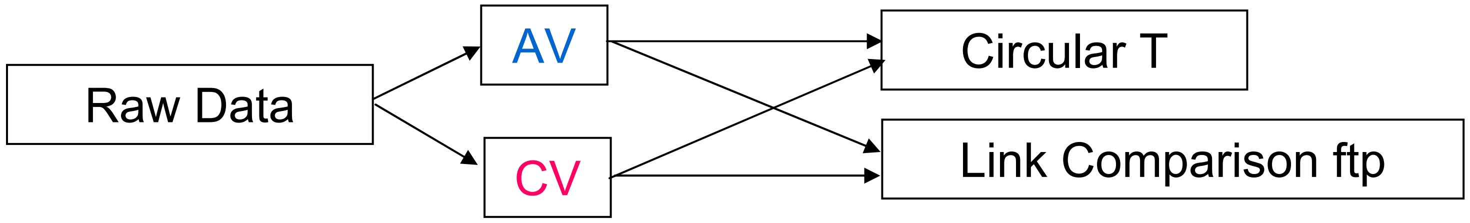
- AV is more advantageous to TAI than CV:
  - Time link stability improved
  - Zero-Influence of the uncertainty of pivot labs: $u_A, u_B \sim 0$
  - Uncertainty of UTC-UTC(k) globally improved *0.1 ~ 1.6 ns, 0.34 ns on average*, with only one exception
  - No need to update receivers, TAI data collection procedures …
- When shift to AV, UTC-UTC(k) of Circular T will change: *-0.1 ~ +1.9 ns* with *mean= +0.3 and r.m.s.= ±0.5 ns*
- Software ready at BIPM: easy switch between AV and CV

Remark: For short distance (<1000 km), CV ~ AV
AV requires rigorous data processing, corrected GPS data available on TAI ftp site
Links and link comparisons also available on TAI ftp site ftp://tai.bipm.org/TimeLink/LkC/

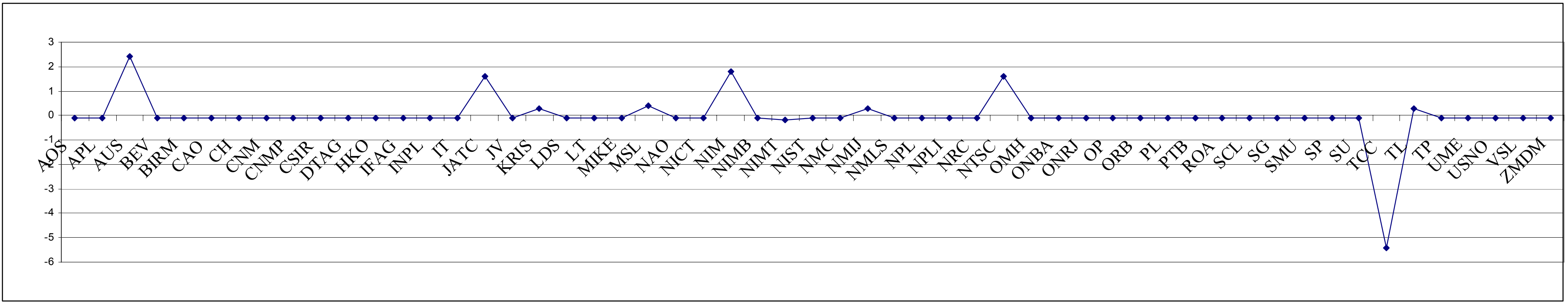
End

Software Tsoft

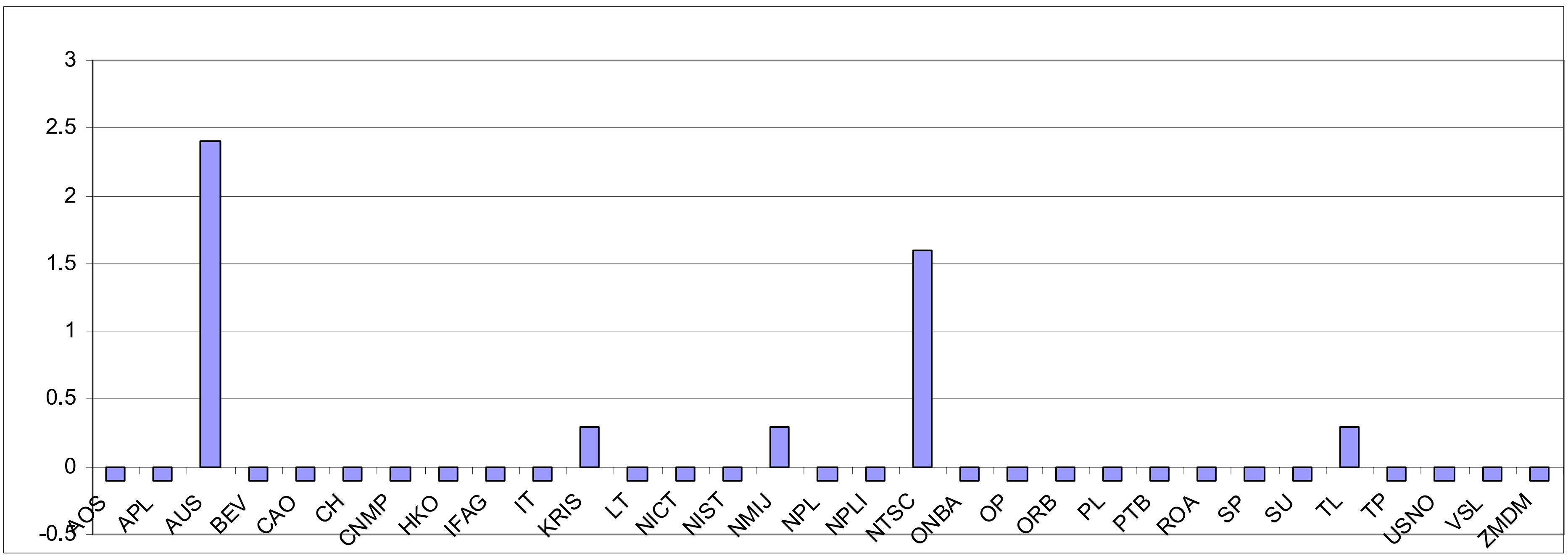
- AV or CV: different processing methods; no need of receiver hardware update
- Fully automatic
- Switch: AV ⇔ CV
  - All CV
  - All AV
  - Mixed CV and AV



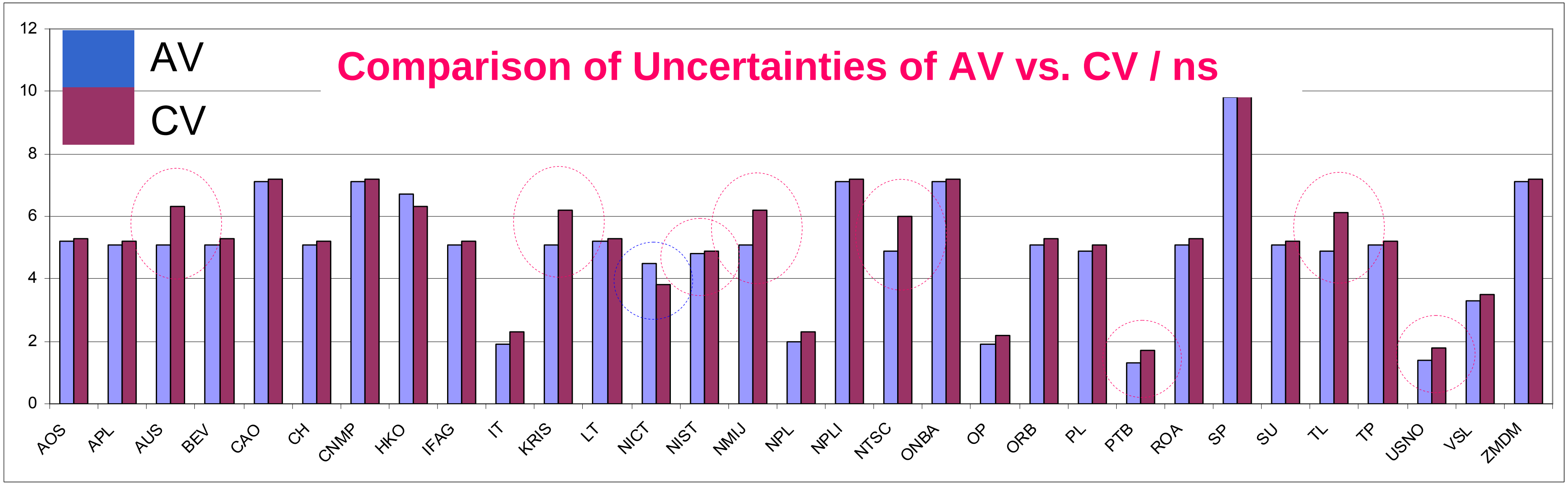
MJD 53884 UTC(AV)-UTC(CV), All Lab with data completed

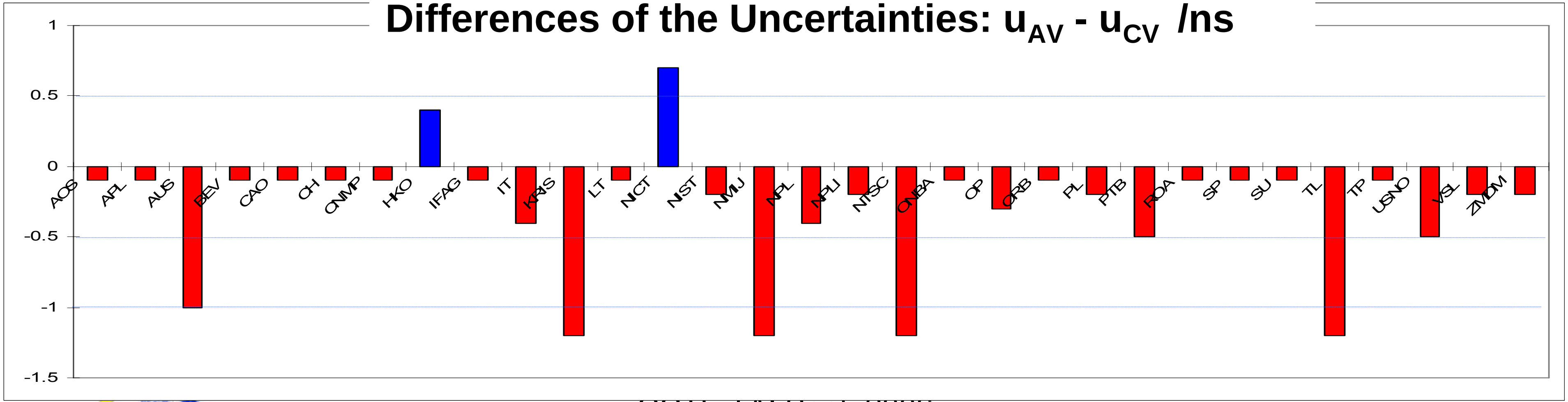


MJD 53884 UTC(AV)-UTC(CV), Lab uB calibrated



Improvement in Total Uncertainty u (4/4) 0605 / CirT221

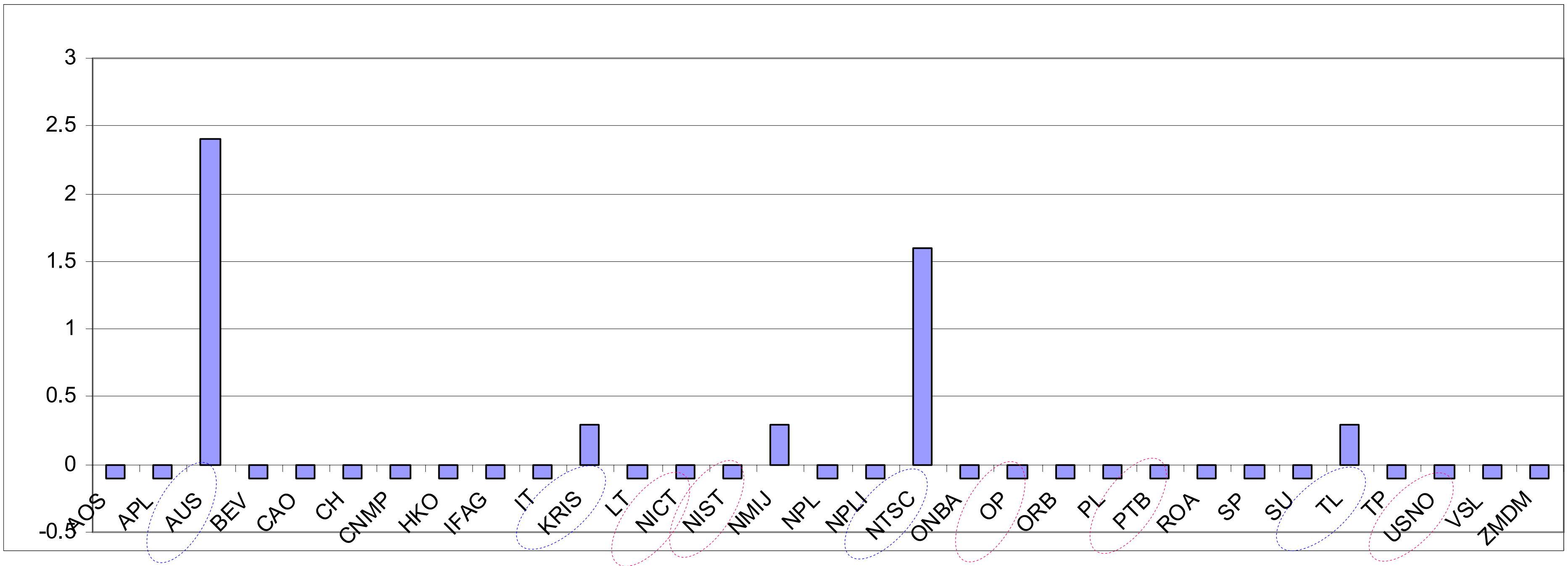




Influence in UTC when shift to AV

UTC(AV)-UTC(CV)

TAI0605, CirT221, MJD 53884



0604

Baseline	Obs. Type	Length km	TW-AV ns	TW-CV ns	PPP-AV ns	PPP-CV ns	Gain ns
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0605

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NICT-PTB	MC	10600	1.857	2.086	2.082	2.333	~ 11 %

0604 uAAV=Min(uACV)

AOS	-0.101	5.401	5.501
APL	-0.2	5.4	5.6
AUS	-1.6	5.4	7.0
BEV	-0.1	5.4	5.5
CAO	-0.1	7.2	7.3
CH	-0.1	5.2	5.3
CNMP	-0.1	8.2	8.3
HKO	0.3*	7.4	7.1
IFAG	-0.1	5.2	5.3
IT	-0.4	1.7	2.1
KRIS	-1.2	5.2	6.4
LT	-0.1	5.4	5.5
NICT	0.5*	4.5	4.0
NIST	-0.2	4.8	5.0
NMIJ	-1.2	5.2	6.4
NPL	-0.4	1.7	2.1
NPLI	-0.3	7.3	7.6
NTSC	-1.6	5.0	6.6
ONBA	-0.1	8.7	8.8
OP	-0.4	1.7	2.1
ORB	-0.1	5.2	5.3
PL	-0.2	5.1	5.3
PTB	-0.5	1.3	1.8
ROA	-0.1	5.2	5.3
SP	-0.3	2.1	2.4
SU	-0.1	5.9	6.0
TL	-1.2	5.0	6.2
TP	-0.1	5.7	5.8
USNO	-0.4	1.5	1.9
VSL	-0.4	1.7	2.1
ZMDM	-0.2	7.5	7.7